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ABUNDANCES OF ACTINIDES AND SHORT-LIVED NONACTINIDES IN THE INTERSTELLAR MEDIUM: DIVERSE SUPERNOVA SOURCES FOR THE *r*-PROCESSES

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ABSTRACT

Abundances of ^{244}Pu, ^{235}U, ^{238}U, and ^{232}Th in the early solar system are about those expected for uniform production over most of galactic history. The inferred abundance of ^{182}Hf is also compatible with this model. We here associate production of ^{182}Hf with the same *r*-process SN sources that produce actinides (SNACS). This requires that *r*-process nucleosynthesis in SNACS took place rather uniformly over the age of the galaxy until $\sim 10^7$ yr prior to solar system formation. The low abundance of ^{107}Pd and ^{129}I in the early solar system indicates that SNACS cannot produce these nuclei at the high yields expected from standard *r*-process models. We propose that there are distinctive SN sources for different *r*-process nuclei with a sharp distinction in different SN contributions below and above $A \sim 140$. Abundances in stars with very low metallicities will vary depending on the type of SN contributing to the local region of star formation. A time scale of $\sim 10^7$ yr is much shorter than the 10^8 yr time usually associated with processes in the galaxy and with the last time of *r*-process injection accounting for ^{129}I, but may be compatible with the rate of SN occurrence. The hypothesis of a nearby SN polluting the protosolar nebula is critically discussed.

Subject headings: ISM: abundances — nuclear reactions, nucleosynthesis, abundances — solar system: formation — stars: formation — supernovae: general

1. INTRODUCTION

The discovery of a deficiency of ^{182}W/^{184}W in iron meteorites by Lee & Halliday (1995) and Jacobsen & Harper (1996) indicates that ^{182}Hf was present in the early solar system with ^{182}Hf/^{180}Hf $\approx 2.8 \times 10^{-4}$. The upper bound of ^{182}Hf/^{180}Hf $\leq 5 \times 10^{-5}$ by Ireland (1991) from a mesosiderite may be due to a later time of formation (see Ireland & Wlotzka 1992; Stewart, Papanastassiou, & Wasserburg 1994). A correlation of ^{182}W with Hf/W, which is necessary to demonstrate the presence of ^{182}Hf, has yet to be found. We here assume the deficit in ^{182}W/^{184}W is due to ^{182}Hf. This observation was hinted at by Harper et al. (1991) and Harper & Jacobsen (1994). Production of ^{182}Hf by *r*- or *s*-processes was investigated by Cameron (1993) and Cameron et al. (1993). Norman & Schramm (1983) proposed ^{182}Hf as an *r*-process chronometer. Wasserburg et al. (1995) investigated AGB sources and found ^{26}Al, ^{107}Pd, ^{41}Ca, and ^{60}Fe can be explained by the special circumstances of injection from a nearby AGB source. However, the ^{182}Hf predicted by Wasserburg et al. (1994, 1995) is low by a factor of 100 with respect to the Hf data due to the low neutron density required to reproduce branchings in the main *s*-component. Gallino et al. (1996) increased this yield times 2. We pursue an analysis of these results assuming ^{182}Hf is an *r*-process product and will show that uniform production of actinides and ^{182}Hf over the history of the galaxy yields self-consistent results which then require distinctive production sites of many *r*-process nuclei. We are not interested here in seeking self-consistent long-term nucleosynthetic chronologies but rather in attempting to estimate abundances of short-lived nuclei in the ISM and relating them to the actinides. Our approach follows Schramm & Wasserburg (1970). Some calculations presented here were given by Cameron (1993), who considered long-term, uniform production. To explain the low ratio $(^{129}\mathrm{I}/^{127}\mathrm{I})_\odot = 10^{-4}$, it is usually assumed that this *r*-process nuclide was the residue of SN ejecta from a time $\sim 10^8$ yr before the solar system formed. This is at odds with the inferred abundance of ^{182}Hf. ^{107}Pd is not a severe constraint as it may be produced by *r*- or *s*-processes.

2. UNIFORM PRODUCTION FOR ACTINIDES

We use ^{232}Th for reference and exhibit $N_i^{\mathrm{AC}}/N_{^{232}\mathrm{Th}}$ for various models. Here N_i^{AC} is the number of actinide (AC) species "*i*." For the limiting case of steady state production of ^{232}Th, ^{238}U, ^{235}U, ^{244}Pu, and ^{247}Cm, we have $N_i^{\mathrm{AC}}/N_{^{232}\mathrm{Th}} = P_i^{\mathrm{AC}}\ \bar{\tau}_i^{\mathrm{AC}}$ where $\bar{\tau}_i^{\mathrm{AC}}$ is the mean lifetime of "*i*" and P_i^{AC} the production rate. Figure 1 shows $N_i^{\mathrm{AC}}/N_{^{232}\mathrm{Th}}$ as a function of $\bar{\tau}_i^{\mathrm{AC}}$ for cases A, steady state reference line with $P_i^{\mathrm{AC}} = P_j^{\mathrm{AC}}$; B, steady state production (SSP) with the factors P_i^{AC} from standard estimates in Schramm & Wasserburg (1970; see Cowan et al. 1991 for other estimates; these rates are not well established); C, uniform production (UP) over a time $T = 10^{10}$ yr using standard production factors; and D, measured (M) or inferred values for the early solar system (cf. summary in Wasserburg 1985). Case C will be called the uniform production (UP) model. The abundances given here are the values immediately after cessation of nucleosynthesis. Figure 1 shows that these results cluster about the steady state reference line and give reasonable agreement between UP and M. $(^{244}\mathrm{Pu}/^{232}\mathrm{Th})_\odot$ is only a

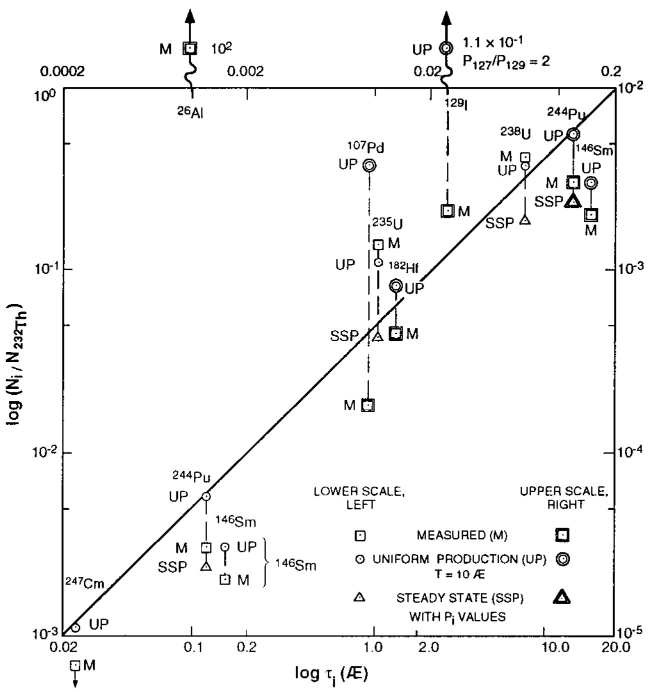

FIG. 1.—Graph of $\log(N_i/N_{232_{\rm Th}})$ vs. $\log \bar{\tau}_i$. Solid line corresponds to steady state with $P_i^{\rm AC}$ = const. For standard production rates, $P_i^{\rm AC}$; △ for SSP; ⊙ for uniform production over 10^{10} yr; and ⊡ for observed values.

factor of 2 below the case for UP. The upper limit for ^{247}Cm/^{232}Th is slightly below UP. Approximate accord between observed ^{244}Pu/^{232}Th and the UP calculation suggests that $P_i^{\rm AC}(T)$ near the time of isolation of the proto–solar nebula 4.56×10^9 yr ago and the longer term average rates ($\langle P_i^{\rm AC}\rangle$) must be equal to within about a factor of 2. The rates ($\langle P_i^{\rm AC}\rangle$) represent time averages of $\sim 2 \times 10^8$ yr for ^{244}Pu, 1×10^9 yr for ^{235}U and 7×10^9 yr for ^{238}U. This shows that actinide production has been roughly constant over galactic history.

3. UNIFORM PRODUCTION FOR NONACTINIDES

We now assume $P_i^r(T)/\langle P_i^r\rangle = 1$ for r-process nuclei that are not actinides and assume they are produced along with the actinides. For stable nuclei we use number abundances ($N_\odot^i$) at 4.56×10^9 from Anders & Grevesse (1989). No yields from models of SNs are used in this section. If such r-process nuclei are produced with the actinides, then the number of radioactive (R) and stable species (S) should be in conformance with the above observations. We take $N_R^r = P_R^r(T)\bar{\tau}_R$, $N_S^r = \langle P_S^r\rangle T$ and $N_{232_{\rm Th}} \approx \langle P_{232_{\rm Th}}\rangle T[1 - T/(2\bar{\tau}_{232})]$. Solar ^{182}W is produced 33% by r-process (Käppeler, Beer, & Wisshak 1989). Gallino et al. (1996) estimate a 57% r-contribution to ^{182}W with updated neutron capture cross sections and stellar AGB models. $^{182}{\rm W}^r$ flows through ^{182}Hf so that $\langle P_{182}^r\rangle T = 0.57\ ^{182}{\rm W}_\odot$ and $^{182}{\rm Hf} = P_{182}^r(T)\bar{\tau}_{182} = 0.57 \times {}^{182}W_\odot \bar{\tau}_{182}/T$. $(^{182}{\rm Hf}/^{180}{\rm Hf})_{\rm UP} = 4.8 \times 10^{-4}$ (relative to $^{180}{\rm Hf}_\odot$). Lee & Halliday (1995) showed that ^{182}W/^{184}W in three iron meteorites is low by 4×10^{-4} relative to chondrites, terrestrial, and lunar rocks. Jacobsen & Harper (1996) also independently established a $-4\ \epsilon$u shift for Toluca iron. As these workers argued, FeNi metal should be highly enriched in W as compared to Hf, so that the deficiency is due to a separation of Hf from metal prior to ^{182}Hf decay. This shift corresponds to $^{182}{\rm Hf}/^{180}{\rm Hf} \approx 2.8 \times 10^{-4}$ at the time of Hf-W fractionation. Agreement between this value and the prediction of our simple model calculation is almost exact. It thus appears consistent that ^{182}Hf is produced with the actinides and extends the UP relationship down to a time $\sim 10^7$ yr. ^{146}Sm and ^{144}Sm are p or (γ, n) products associated with SN (Woosley & Howard 1978). Assuming $P_{146}^p/P_{144}^p \sim 1$, this result agrees with the observations and calculations of Cameron (1993). For ^{135}Cs, considering s contributions to ^{135}Ba and ^{133}Cs, we obtain the results in Table 1. For ^{129}I with $P_{129}^r/P_{127}^r = 2$ we obtain values for both $(^{129}{\rm I}/^{127}{\rm I})_{\rm UP}$ and $(^{129}{\rm I}/^{232}{\rm Th})_{\rm UP}$ that are far in excess of the observations. Cameron (1993) chose to cut off r-process sources $\sim 10^8$ yr before formation of the solar system to explain the low $(^{129}{\rm I}/^{127}{\rm I})_\odot$ by free decay. This approach has been the one preferred by most workers. For ^{107}Pd with ^{110}Pd (pure-r) as reference, we obtain values far above those observed. For ^{60}Fe we can only establish an upper bound with this approach. (For results using SN yields, see next section). Results for ^{182}Hf and ^{146}Sm appear to be in consonance with UP production of the actinides and suggest they are produced in a common type of SN source. We define these supernova sources that produce the actinides as supernova actinide sources (SNACS). These considerations for ^{182}Hf would require ongoing SNACS contributions to the placental ISM to within $\sim$10 Myr of its isolation. In contrast, ^{129}I and ^{107}Pd can not be correlated with this source at the usual yields as they would be grossly overproduced. We infer that the standard r-process production of nuclei $A \lesssim 140$ must originate in different SN sources which must have been quiescent for 10^8 yr prior to isolation of the placental solar cloud.

4. THE CASE OF ^{53}Mn AND ^{60}Fe AT UP

Here we use yields from SN models. Analysis of the iron group nuclei is given by Timmes et al. (1995). Using production ratios of ^{53}Mn and ^{55}Mn calculated by Woosley & Weaver

TABLE 1

ABUNDANCES OF SHORT-LIVED NUCLEI NONACTINIDES[a]

R; S	$\bar{\tau}_R$ (Myr)	$N_S^\odot$	$(N_R/N_S)_{\rm UP}$	$(N_R/N_S)_\odot$[b]	$(N_R/N_{232_{\rm Th}})_{\rm UP}$	$(N_R/N_{232_{\rm Th}})_\odot$
^{182}Hf; ^{180}Hf	13	0.0541	4.8×10^{-4}	2.8×10^{-4}	6.2×10^{-4}	3.6×10^{-4}
^{146}Sm; ^{144}Sm	145	0.0080	1.5×10^{-2}	1.0×10^{-2}	2.9×10^{-3}	1.9×10^{-3}
^{129}I; ^{127}I	23	0.90	5×10^{-3}	1.0×10^{-4}	1.1×10^{-1}	2.1×10^{-3}
^{107}Pd; ^{110}Pd	9.4	0.163	1.4×10^{-3}	4.5×10^{-5}	5.5×10^{-3}	1.8×10^{-4}
^{135}Cs; ^{133}Cs	3.3	0.372	2.1×10^{-4}	1.6×10^{-4}(?)	1.9×10^{-3}	...
^{60}Fe; ^{56}Fe	2.2	8.25×10^5	$<3.4 \times 10^{-6}$	$\sim 10^{-8}$	...	...

[a] UP for $T = 10^{10}$ yr.

[b] Nominal solar system values. These will reflect different formation times. A question mark denotes a value based on ^{135}Ba deficiency (McCulloch & Wasserburg 1978) and is not unambiguously assignable to ^{135}Cs.

TABLE 2

Uniform Production[a]

R; S	$\bar{\tau}_R$ (Myr)	P_R/P_S	$(N_R/N_S)_{\rm UP}$	$(N_R/N_S)_{\rm UP}e^{-2/\bar{\tau}_R}$	$(N_R/N_S)_\odot$
^{60}Fe; ^{56}Fe	2.2	1.2×10^{-4}	2.6×10^{-8}	1.0×10^{-8}	$\sim 10^{-8}$
^{53}Mn; ^{55}Mn	5.3	0.19	1.0×10^{-4}	6.8×10^{-5}	6.7×10^{-5}
^{26}Al; ^{27}Al	1.1	5.4×10^{-3}	5.9×10^{-7}	9.4×10^{-8}	5×10^{-5}
^{41}Ca; ^{40}Ca	0.15	1.4×10^{-3}	2.1×10^{-8}	3×10^{-14}	$\sim 1.5 \times 10^{-8}$

[a] P_R/P_S were obtained by summing all the respective nuclei R and S and their progenitors in the total exterior envelope as given by Woosley & Weaver 1995 for a 25 $M_\odot$ SN.

(1995, henceforth WW95) for a model 25 $M_\odot$ SN, we obtain $P_{53}/P_{55} = 0.19$, which is in accord with the *e*-process estimate of 0.13 by Cameron (1993). We obtain ^{53}Mn/^{55}Mn $= 0.19 \times 5.3 \times (10^6/10^{10}) = 1.0 \times 10^{-4}$ at UP. If all ^{55}Mn is produced this way, then this means that ^{53}Cr in the ISM must be depleted by $1.0 \times 10^{-4} \times [(^{55}\mathrm{Mn})_\odot/(^{53}\mathrm{Cr})_\odot] = 7.5 \times 10^{-4}$. There would thus be a 7.5 ϵu (1 ϵu = 0.01%) shortfall in ^{53}Cr relative to that of modern Cr if UP were achieved in the ISM. Such an effect appears to be required by the results of Birck & Allègre (1985), who discovered the presence of ^{53}Mn, with ^{53}Mn/^{55}Mn $= (6.7 \pm 2.2) \times 10^{-5}$ in samples of calcium-aluminum–rich inclusions (CAI) from a correlation of ^{53}Cr/^{52}Cr with an initial ^{53}Cr/^{52}Cr of -2 ϵu. These samples also have ^{54}Cr anomalies, indicating incomplete mixing. There is a coincidence between the UP calculation (for $\Delta t = 0$) and these observations on CAI. Meteorites that are the product of early planetary processes give ^{53}Mn/^{55}Mn $\sim 10^{-6}$ (Hutcheon et al. 1992; Rotaru, Birck, & Allègre 1992; Lugmair et al. 1994). For these bodies, ^{53}Mn $-$ ^{53}Cr systematics must reflect reequilibration during their cooling. The high $(^{53}\mathrm{Mn}/^{53}\mathrm{Cr})_\odot$ results could explain smaller effects (0.5–1.0 ϵu) found by Rotaru et al. (1992) and Lugmair et al. (1994) for ^{53}Cr/^{52}Cr in *bulk* Cr from meteorites that could represent different times of protoplanet formation with Mn-Cr fractionation. Analogous results for UP for ^{60}Fe, ^{26}Al, and ^{41}Ca (see Table 2) were obtained using yields from WW95.

5. MEAN LIFETIMES AND FREQUENCY OF SN

Whether the UP treatment is a reasonable approach depends upon the frequency of occurrence of SN sources and the time scales required by different nuclear species. We consider that condensation of the solar nebula from the ISM is rapid ($\sim 10^6$ yr). The time (Δt) between cessation of UP and condensation of the solar nebula is a critical parameter. We consider that SN occur randomly throughout the galaxy and find a relationship between $\bar{\tau}_R$ and the domains that must be refreshed in order that species "R" is replenished with a frequency $1/\bar{\tau}_R$ in that region. Consider two simple cases: (1) The galaxy of volume V_G and mass M_G is divided into unit volumes ΔV; or (2) unit mass assemblages ΔM. Let the rate SN occur in the galaxy per year be Q. Then for case 1 we have $V_G/(\Delta V \bar{\tau}_R) = Q f_{\rm SNAC}$ or for case 2, $M_G/(\Delta M \bar{\tau}_R) = Q f_{\rm SNAC}$. Here $f_{\rm SNAC}$ is the fraction of SN producing actinides. We take $f_{\rm SNAC} \sim 1$. For $V_G \approx 7 \times 10^2$ (kpc)^3 or $M_G \approx 10^{11}$ $M_\odot$ and taking $Q \sim 3 \times 10^{-2}$ yr^{-1}, we have: case 1, $\Delta V = 2 \times 10^4/\bar{\tau}_r$; case 2: $\Delta M = 3.3 \times 10^{12}$ $M_\odot/\bar{\tau}_R$. Using ^{182}Hf as a guide, we obtain $\Delta V_{\rm Hf} \approx 2 \times 10^{-3}$ (kpc)^3, corresponding to a linear scale of 120 pc or $\Delta M_{\rm Hf} = 2.6 \times 10^5$ $M_\odot$, the size or masses typical of a giant molecular cloud; if we consider only the mass of gas at 4.5×10^{10} yr, then $\Delta M_{\rm Hf} = 2.6 \times 10^4$ $M_\odot$. These calculations suggest it is plausible for smaller regions of the galaxy, on average, through random discrete events, to have a regular supply of fresh material not greatly different from a quasi–steady state over a timescale of $\sim 10^7$ yr. This is much shorter than the 10^8 yr timescale usually assumed. It also suggests that the "local" nucleosynthetic average could be about the same as the galactic average. Lifetimes of giant molecular clouds are considered to be shorter than 4×10^7 yr. The time to grow a molecular cloud is less than $\sim 2 \times 10^8$ yr (see Turner 1988). The UP model for ^{182}Hf implies that clouds are replenished on a timescale of $\sim 10^7$ yr with fresh SN debris. While the above estimates cannot provide a basis for justifying a UP model, they do not indicate a radical disparity in scales. The dispersion and mixing that we are discussing is that of the gas and dust, not directly that of the stars. The timescale for mixing in the galaxy is usually taken to be the order of a galactic year ($\sim 3 \times 10^8$ yr) or 5×10^7 yr from the shear rate. The timescales considered here are much shorter. Mixing of the gas over distances of 100 pc are plausibly achieved over 10^7 yr with a velocity of $\sim$10–15 km s^{-1}, but this requires a driving force (SN winds; Cameron et al. 1995). This distance is much larger than the range for snow plow slowing of SN expansion ($\sim$6 pc).

6. LATE STAGE INJECTION

We now compare a late-stage SN injection as a source and a trigger to solar system formation as proposed by other workers. There are no reliable estimates of SN yields for many nuclides. We follow the notation of Wasserburg et al. (1995) and assume that late-stage addition of stable nuclei is small. For instantaneous injection and mixing of SN debris with some mass of the ISM assuming that R and S are purely SN *r*-products:

$$N_R^\odot/N_S^\odot = q_R^{\rm SN} M_{\rm SN}^E/N_S^\odot = (P_R/P_S)(q_S^{\rm SN}/q_S^\odot)(M_{\rm SN}^E/M_\odot)\,. \quad (1)$$

Here $q_i^{\rm SN}$ is the weight fraction in SN ejecta of isotope i, $M_{\rm SN}^E$ is the total mass of SN ejecta diluted in the protosolar mass $M_\odot$, and $q_S^\odot$ is the solar abundance. P_R and P_S are the net production rates of R and S. For ^{53}Mn, we find $q_{55}^{\rm SN}/q_{55}^\odot \approx 5$ from WW95 for SN from 11 to 25 $M_\odot$. This includes contributions from ^{53}Mn, ^{53}Fe, ^{55}Mn, ^{55}Fe, and ^{55}Co. To match $(^{53}\mathrm{Mn}/^{55}\mathrm{Mn})_\odot$, we obtain $M_{\rm SN}^E/M_\odot \approx 10^{-4}$. For ^{60}Fe, $q_{56}^{\rm SN}/q_{56}^\odot \approx 5$ and $P_{60}/P_{56} = 1.3 \times 10^{-4}$ (WW95). This gives $(^{60}\mathrm{Fe}/^{56}\mathrm{Fe}) = 6 \times 10^{-8}$, which would decay to 4×10^{-9} in a time of 6×10^6 yr. This is in reasonable accord with the value reported by Shukolyukov & Lugmair (1993). For ^{182}Hf, ^{107}Pd, and ^{129}I, we have no SN yields. Following the standard approach, we would expect that for pure *r*-nuclei all produced in a uniform source that $q_i^{\rm SN}/q_i^\odot$ should be constant ($\approx$5). To match $(^{129}\mathrm{I}/^{127}\mathrm{I})_\odot = 10^{-4}$ with $M_{\rm SN}^E/M_\odot \approx 10^{-4}$ implies $q_{127}^{\rm SN}/q_{127}^\odot \sim 0.5$. Woosley et al. (1994) estimate $q_{127}^{\rm SN}/q_{127}^\odot \sim 13$. If we consider stable *r*-process nuclei in the solar system to be produced by the standard SN source, then $q_S^{SN}/q_S^{\odot}$ is a constant for all species S. It follows that for pure r-process nuclei (R and S), $N_R^{\odot}/N_S^{\odot}$ is determined if we know P_R/P_S. If we assume $q_S^{SN}/q_S^{\odot} \sim 5$ and $M_{SN}^E/M_{\odot} \approx 10^{-4}$, we obtain abundances in the solar nebula of $^{53}Mn/^{55}Mn = 10^{-4}$, $^{60}Fe/^{56}Fe = 6 \times 10^{-8}$, $^{129}I/^{127}I = 10^{-3}$, and $^{107}Pd/^{110}Pd = 8 \times 10^{-4}$. For ^{182}Hf, as only a fraction F of $^{182}W_{\odot}$ is from ^{182}Hf decay, we have $F_{182_W}^{\odot} q_{182}^{\odot}/q_{182}^{SN} = q_S^{\odot}/q_S^{SN}$. So for late injection: $N_{182_{Hf}}/N_{182_W}^{\odot} \approx (q_{182}^{SN} M_{SN}^E/q_{182_W}^{\odot} M_{\odot}) = F_{182_W}^{\odot}(q_{56}^{SN}/q_{56}^{\odot})(M_{SN}^E/M_{\odot})$ and $N_{182_{Hf}}/N_{182_W}^{\odot} = (0.57)(5)\ M_{SN}^E/M_{\odot} = 2.8 \times 10^{-4}$ in accord with observations. Had we chosen to match $^{129}I/^{127}I$, then $M_{SN}^E/M_{\odot} \approx 10^{-5}$ and ^{182}Hf, ^{53}Mn, and ^{60}Fe would be low by a factor of 10. It follows that there is no self-consistent scenario for either late addition or UP that can explain both ^{129}I and ^{107}Pd and the shorter lived nuclides. In summary, late addition of SN ejecta could provide sufficient ^{182}Hf, ^{53}Mn, and ^{60}Fe to the local ISM, but this also requires that ^{129}I and ^{107}Pd are not produced at the expected amounts in that SN. Conversely, if ^{129}I is the result of late SN injection in the usually expected amounts, then ^{182}Hf, ^{107}Pd, ^{53}Mn, and ^{60}Fe, cannot be provided by this source.

7. CONCLUSIONS

The inferred abundance of ^{182}Hf in the early solar nebula is comparable to that produced by uniform long-term r-process nucleosynthesis in those supernovae that made actinides (SNACS). This abundance is the value at the instant of termination of the assumed long-term, uniform production (UP), injection, and mixing of SN debris. The ^{146}Sm abundance is compatible with this UP model. Insofar as r-process production of ^{182}Hf gives $(^{182}Hf/^{180}Hf)_{UP} \gtrsim 2(^{182}Hf/^{180}Hf)_{\odot}$, then there is $\Delta t \sim 10^7$ yr available between the last production and removal of the protostellar mass from the ISM. In this case, the shorter lived nuclei would have substantially decayed. The estimated value of $^{182}Hf/^{180}Hf$ is very close to the observed $^{182}W/^{184}W$ shift and may not permit so long a Δt. ^{129}I and ^{107}Pd were present in the solar system at far lower abundances than calculated for the UP model. This implies that ^{129}I and ^{107}Pd are not from SNACS but are produced elsewhere. This problem is not alleviated by late-stage addition of fresh SN debris but again requires that the r-process is not the same in different SN. One possibility is that ^{129}I and ^{107}Pd are produced at low levels in SNACS to provide the observed abundances, but that the bulk of ^{127}I is still produced in another SN source. Note that there is no a priori basis for assuming that yields inferred for the actinides and ^{182}Hf should be associated with any specific SN models currently available. Using yields from WW95, ^{53}Mn and ^{60}Fe would be present at $\Delta t = 0$ (SN trigger), but after 10^7 yr, the abundance would have dropped below the early solar system values. It has been argued from sharpness of the r-process peaks (Burbidge et al. 1957) associated with neutron closed shells at $N - 82$ and 126, that the r-process is "robust" and results from a well-defined environment, rather than some combination of different sites. This view has associated all r-process production with a "classical" (n, γ) equilibrium environment. However, as parenthetically noted by Mathews & Cowan (1990), the possibility of "secondary" r-processes cannot be excluded. The nuclear reactions during the complex transport processes clearly will change some r-process yields (cf. Burrows, Hayes, & Fryxell 1995). From the viewpoint given here for UP, we argue that there are sources for producing the actinides, ^{182}Hf and ^{146}Sm that are distinctive from the sources for production of intermediate mass r-process nuclei. Our principle conclusion is that UP down to a timescale of $\sim 10^7$ yr may provide the heaviest $A > 140$ nuclei in this scenario if all the r-process nuclei are not all produced in the same uniform, "classical" r-source. Abundances in stars with very low metallicities that are associated with early galactic history will be highly susceptible to the particular type of SN contaminating the medium from which they formed. The study of ultra metal poor stars (cf. Sneden et al. 1996) shows some startling abundance patterns, sometimes with subsolar Th abundances. Abundance patterns reported by Cowan et al. (1996) may reflect compositions of both r and s processes that are not the average solar system values but come from contributions from nonstandard r- and low-metallicity s-process sources. The patterns may, in part, reflect the nature of a particular SN source where nuclei produced are far different from the long-term solar system average. The full inventory of short-lived nuclei in the solar nebula requires multiple sources and some "special" events involving very late-stage injection from SN, AGB, galactic cosmic rays, or local bombardment during a T Tauri phase. Substantial production of ^{53}Mn, ^{26}Al as well as Li, Be, and B, may be expected from energetic particles in the ISM (Ramaty, Kozlovsky, & Lingenfelter 1995; Clayton & Jin, 1995).

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